The Loop Current as a Vector for Connectivity of Invasive Species from the Western Atlantic to the Gulf of Mexico

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ABSTRACT

The Loop Current (LC) in the Gulf of Mexico (GOM) is part of the North Atlantic western boundary current. With speeds in excess of 2 m/s, the LC intrudes northward into the GOM basin carrying warm, salty, oligitrophic Atlantic and Caribbean Water. Spin-off eddies and entrainment of LC water into the deep GOM basin provides a natural vector for Atlantic and Caribbean species to enter the Gulf by transport of larvae, juveniles or adults. Previous studies have linked the year 2000 invasion of jellyfish, *Phyllorhiza punctata*, in the Mississippi Bight to transport by the LC. In this study we examine potential routes between the LC and the continental shelves of the northern GOM. Satellite tracked drifters pathways are examined to determine routes from the Caribbean through the Yucatan Straits into the GOM. Drifters and model results are further examined for potential routes between the LC and the northern GOM shelves. We found that this vector for non-endemic species is possible, but not as common as might be expected.

KEY WORDS: Invasive, transport, Loop Current, Gulf of Mexico, drifters

La Corriente del Golfo de Méjico como un Vector para conectividad de Especies Invasivas del Atlántico Occidental al Golfo de Méjico

La corriente del Golfo de Méjico forma parte de la corriente occidental del Atlántico Norte. Con velocidades superiores a 2 m/s, esta corriente transporta agua caliente, salada, y oligotrófica del Atlántico y el Caribe hacia el norte. Los remolinos aislados de agua que se desprenden de la corriente penetran en lo profundo del Golfo de Méjico, lo cual provee un transporte natural para ingresar al Golfo a las larvas, los juveniles o los adultos de las especies del atlántico y el Caribe. Los estudios previos han relacionado la invasión de medusas, Phyllorhiza punctata, en el año 2000 con su transporte por parte de la corriente del Golfo de Méjico a la ensenada de Mississippi. En este estudio examinamos las rutas potenciales entre la corriente y la plataforma continental del norte del Golfo de Méjico. El recorrido seguido por los flotadores satélites se examinan con el fin de determinar las rutas desde el Caribe através del Estrecho de Yucatán y en el Golfo de Méjico. Los resultados de los flotadores y los modelos se examinan más en detalle para detectar las rutas potenciales entre la corriente y la plataforma continental del norte del Golfo de Méjico. Encontramos que la dirección de la invasión de esta especie no endémica es posible, pero no es tan común como pudiera esperarse.

PALABRAS CLAVES: Invasivo, transporte, corriente, Méjico, flotadores

INTRODUCTION

The Loop Current in the Gulf of Mexico (GOM) is part of the north Atlantic's western boundary current. Entering the GOM through the Yucatan Channel, it carries warm, salty Caribbean waters into the deep central GOM before looping back southward and exiting the through the Straits of Florida and into the north Atlantic (Figure 1). As a dynamically unstable current (Hurlbert and Thompson, 1980), it periodically cycles through a process of strong intrusion before turning back on itself and breaking off as a large anti-cyclonic spin-off eddy. After break-off, the Loop Current reconnects to itself while the detached eddy migrates into the western GOM where it decays over a period of many months. Spin-off eddies, and detrainment around the Loop Current, act as mechanisms for transfer of tropical waters and their biological content into the shallower waters of the GOM. In this study, a large data set of satellite tracked mixed layer drifters is used to examine advective transport through the Inter-American Seas as a vector of non-endemic species transport into the GOM.

Anthropogenic vectors are not unique as pathways for transporting invasive species. The life histories of many marine species include advective transport as part of their evolutionary development. This natural capability to explore new geographical niches may be essential for long term species survival over geological time scales which include rapid climate changes (McConaugha 1992). In addition to an advective pathway, successful invasion of non-endemic species into a new geographical niche requires advective distances comparable to developmental time scales, potential ecological niches suitable for habitation along the path and sufficient population size for reproduction (Scheltema 1966, 1971). This study addresses the abiotic advective transport portion of the problem. It is recognized that this study could be applied to non-endemic species progressing by steps through the Atlantic and Inter-American Seas or anthropogenically introduced along the pathway.

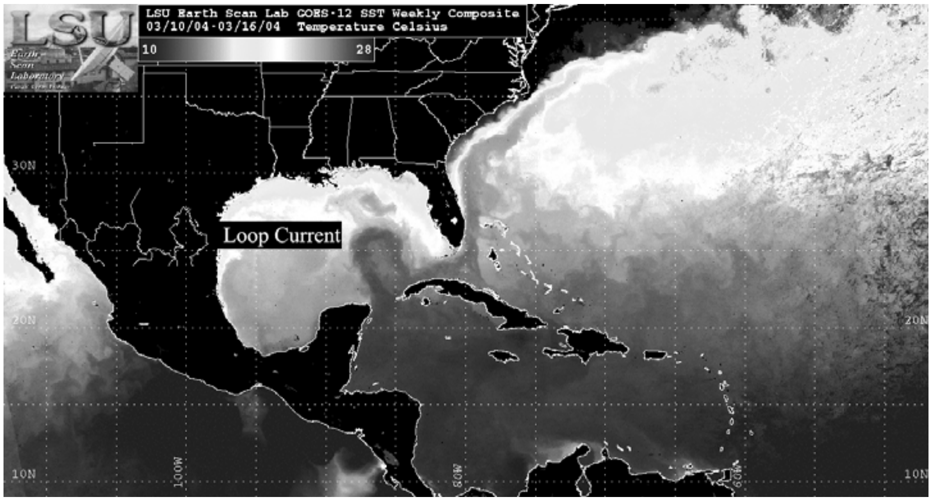

Figure 1. Satellite thermal imagery showing intrusion of Loop Current into the Gulf of Mexico. Weekly composite by LSU Earth Scan Lab from March, 2004.

METHODS

In 1982, the World Climate Research Program recognized the need for a global array of drifting buoys to measure ocean currents in the surface mixed layer. To address this issue, the Global Drifter Program began with the development of inexpensive, easily deployable satellite tracked drifters. Low windage surface floats containing ARGOS satellite transmitters are deployed with 'holey sock' drogues at about 15 m depth. Several location fixes per day for each drifting buoy are acquired worldwide, and sent to the National Ocean and Atmospheric Agency's Atlantic Oceanographic and Meteorological Laboratory in Miami, Florida, for processing. Quality control checks are made, location fixes are interpolated to six hourly positions and surface velocities computed (Lumpkin and Pazos 2006). The data files are freely available for downloading from the NOAA/AOML Data Assembly Center.

The data set included 11,939 drifters deployed world wide between February, 1979 and February, 2008. From this set 2,567 drifters were extracted which were deployed in the Atlantic north of the equator or crossed into the north Atlantic from south of the equator (Figure 2). This number excluded drifters in the Mediterranean, Baltic and Greenland/Iceland/Norwegian Seas. Since we are interested in advection into the GOM, drifters deployed in the GOM were also excluded.

Mixed layer currents, derived from the drifter data set are non-uniform in both space and time. In order to extract patterns of principal currents from this set, a grid was created with points at 0.3 degrees latitude and longitude (~33 km). Current vectors were weighted and averaged at each grid point using an exponentially decaying weighting scheme (objective interpolation; Bretherton *et al*. 1976), with 20 km as the correlation scale and a cut-off of 50 km:

$$w_i = \exp[-(d_i/r_d)^2]$$

Where:
w_i is the weight applied to the current vector from drifter i,
d_i is the distance in km of i from the grid point, and
r_d is a correlation scale.

This produces a highly effective smoothing over space and time and is only possible because of the relatively high density of data points.

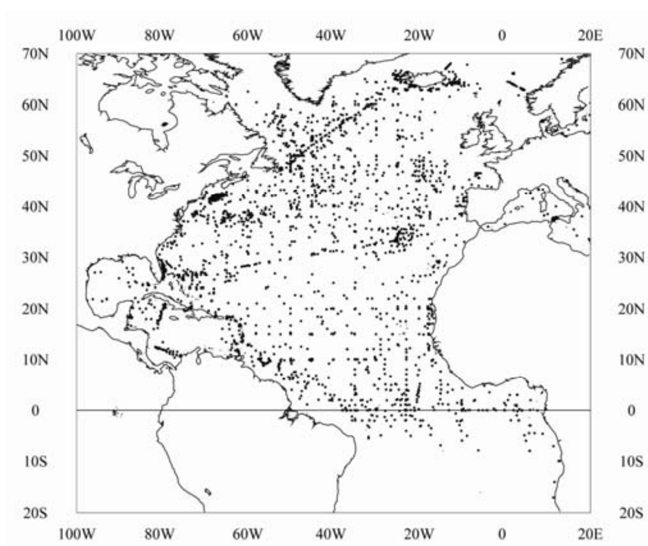

Figure 2. First-report locations of mixed-layer satellite tracked drifters deployed in the North Atlantic/Caribbean/ Gulf of Mexico from 1979-2008 (from NOAA/AOML Data Assembly Center).

RESULTS

All drifters that entered the GOM from the Atlantic and Caribbean Seas were isolated and their 6-hourly positions plotted (Figure 3). Of the 2,536 drifters in the north Atlantic data set, only 46 entered the GOM (1.8%). Most of those that entered came from low latitudes in the Atlantic, drifting with the North Equatorial Current, the North Brazil Current and the Guiana Current, through the Windward Island passages into the Caribbean Current and passing through the Yucatan Channel. The times for transition through the Caribbean Sea from the Windward Island passages into the GOM at the Yucatan Channel ranged from 85 to 306 days with an average of 175 days. This time scale is fairly long for many species which broadcast their larvae, but the route passes shallow water locations where temporary habitats may be found.

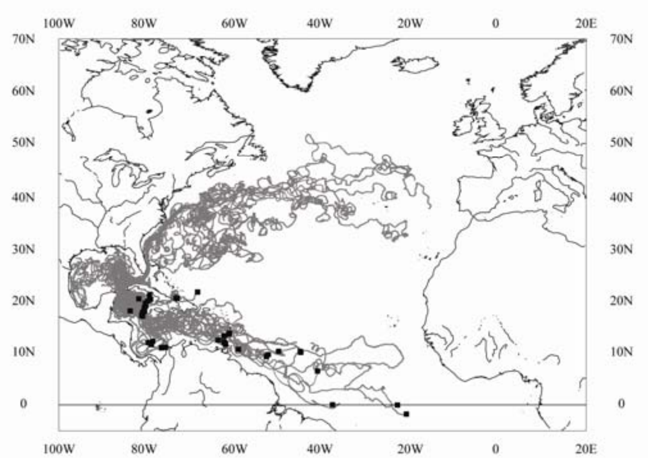

Figure 3. Tracks of mixed-layer drifters entering the Gulf of Mexico from deployments in the Atlantic and Caribbean Seas. Dark squares are first-report locations.

One of the drifters that entered the GOM came into the Caribbean Sea through the Mona Passage, between the Dominican Republic and Puerto Rico, and three drifters came through the Windward Passage between Cuba and Haiti. Two of the latter were deployed in the Windward Passage. These two took 72 days and 84 days respectively to reach the Yucatan Channel.

The drifter that came into the GOM via the Mona Passage (drifter #9815989) is of special interest since its date of arrival (9 May 2000) in shallow waters off the tip of western Florida coincided with the sudden appearance there of millions of exotic jellyfish *Phyllorhiza punctata* von Lendenfeld, 1884 (family Mastigiidae). Significant ecological impacts of this invasion were documented in Graham *et al.* (2003a,b). Subsequent study (Johnson *et al.* 2005) using nowcast/forecast model currents to backtrack from jellyfish arrival showed connection with the Loop Current and the potential for entering the GOM through the Yucatan Channel.

The track of this drifter (Figure 4) tends to validate the Loop Current as a natural invasion route into the northern GOM. However, even if the drifter, itself were closely associated with the jellyfish transport, it is difficult to discern where their ephyra may have entered the pathway. This drifter took 197 days to travel from the Mona Passage to the 200 m isobath in the northern GOM. During this transit time, the drifter entered the shallow waters of Puerto Rico, the Dominican Republic, and Jamaica as well as the eastern length of the Yucatan Peninsula. Jellyfish or their ephyra could have been entrained at many points along the path.

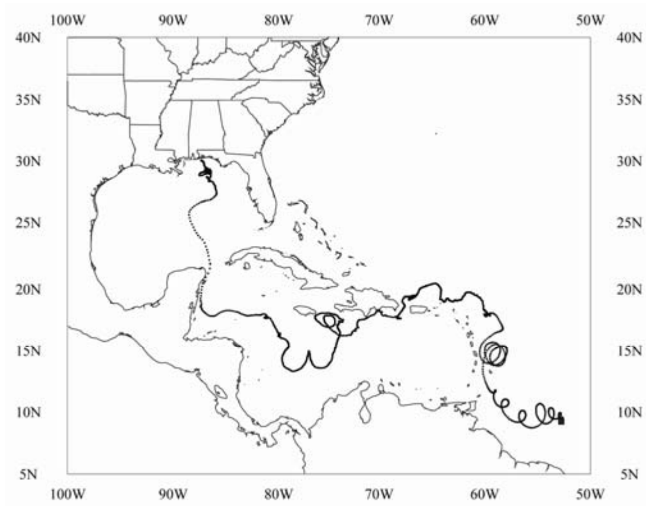

Figure 4. Track of drifter passing through the Caribbean Sea and grounding in the northern Gulf of Mexico coincident with the May 2000 arrival of exotic jellyfish *Phyllorhiza punctata* with its significant ecological impact.

Of the 46 drifters that entered the GOM, 16 crossed the continental shelf break (200 m) into shallower waters (Figure 5). Twelve of these 16 drifters crossed the shelf break around the Yucatan Channel/Campeche Banks and the Florida Keys. Only 4 of the 16 drifters passed into the interior of the basin and then crossed the continental shelf break. This includes the drifter just discussed which may have been associated with the jellyfish bloom of 2000. Locations of first crossings of these 4 drifters onto the continental shelf were widely scattered around the basin (Figure 5). Crossings from the Campeche Banks to the 4 shallow water locations around the GOM took 96 days to northern Mexico/southern Texas, 65 days to the Texas shelf south of Galveston, 42 days to the tip of western Florida and 44 days to the west Florida shelf south of Tampa.

Drift pathways through the Caribbean Sea principally involve the Caribbean Current and its feeder streams (Figure 6). After passing through the Windward Island passages, the Caribbean Current can be observed forming along the Venezuelan coast where it encounters shallow waters and potential settling sites. Off the coasts of Honduras/Nicaragua, the flow passes over the shallow

Mosquitia Banks/Nicaragua Rise, and then encounters shallow waters along the eastern side of the Yucatan Peninsula before entering the GOM. Based on 11 drifters, the average time of transit from the Windward Islands to Guajira Peninsula, Venezuela is 76 days, from Guajira Peninsula to the Mosquitia Banks is 85 days and from Mosquitia Banks to the Yucatan Channel is 24 days.

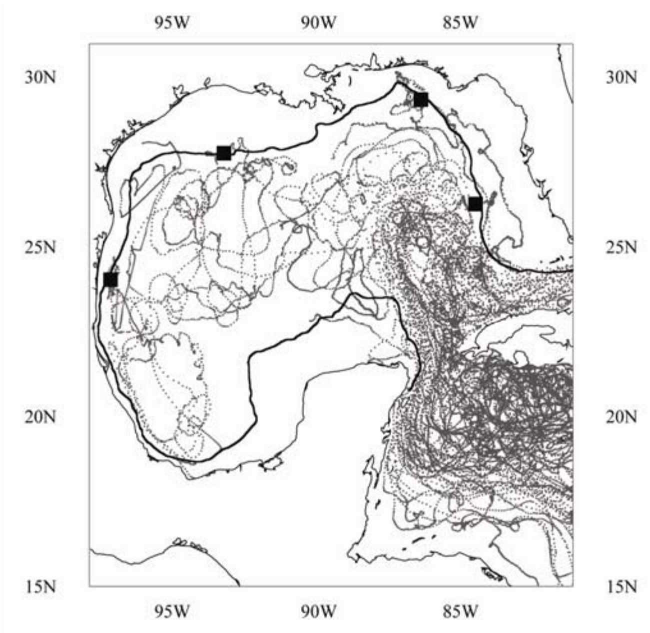

Figure 5. Tracks of drifters that entered the Gulf of Mexico from the Caribbean Sea. Four of these crossed onto the continental shelf in the northern Gulf (black squares).

The principal feeder streams into the Caribbean Current occur through the Windward Passage between Cuba and Haiti, and along the south coasts of Puerto Rico and the Dominican Republic. This latter stream appears to enter the Caribbean Sea through the Windward Islands and then spread northward. There is a fairly strong cyclonic circulation in the Colombian Basin which sweeps the coasts of Central American including the Panama Canal Zone, and reenters the Caribbean Current. These feeder streams contribute additional pathways from potential intermediate stopover points throughout the Inter-American Seas.

SUMMARY AND DISCUSSION

Using a large data base of satellite tracked surface mixed layer drifting buoys, pathways for advective transport of non-indigenous species into the GOM, and possibilities of spread throughout the GOM basin have been explored. With the looming potential of climate change, vulnerability is especially high to species which broadcast their larvae, depending on ocean currents for distribution. In addition, these pathways open the potential for long-distance spreading of anthropogenic introductions anywhere along the path.

Of the 2,536 drifters in the North Atlantic Ocean that were examined, only 46 entered the GOM. This is a surprisingly small number (1.8%). Most of the 46 came from low latitudes in the Atlantic, through the Windward Island passages into the Caribbean Sea and drifting with

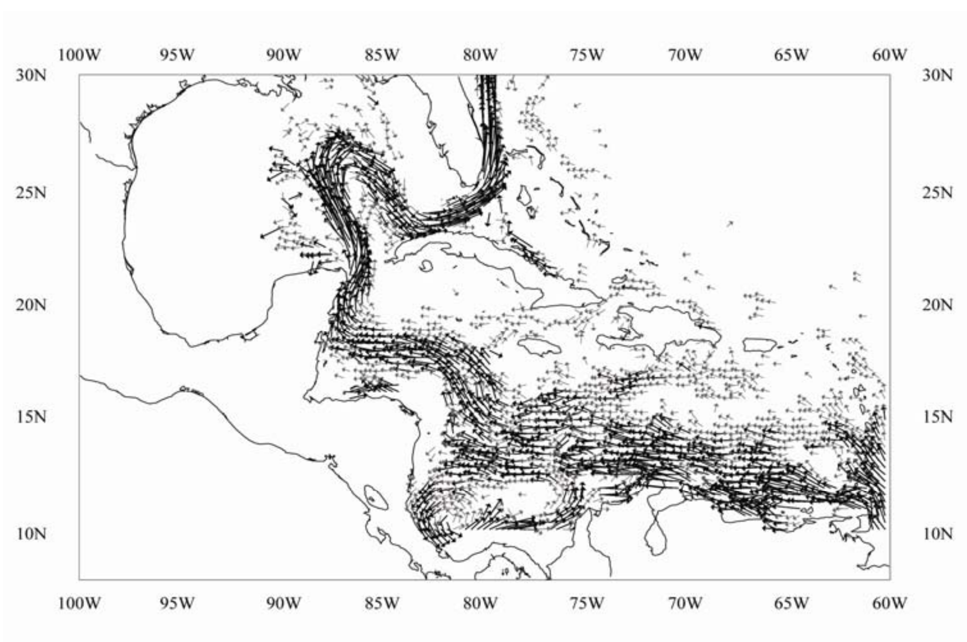

Figure 6. Gridded and optimally interpolated currents from the drifter data set. Currents greater than 40 cm/s are black; currents between 30-40 cm/s are grey. The Caribbean Current and its several feeder streams are clearly visible in this representation.

the Caribbean Current to the Yucatan Channel. Considering biological development times together with drift time scales, the area of coverage for advective transport into the GOM appears to be concentrated in the western tropical Atlantic, north of the equator. Drift times between shallow water areas along the Caribbean Current were roughly one to two months, providing ample opportunity for shallow water species with shorter developmental time scales to find habitation once they entered the Caribbean Sea..

Considering those drifters that entered the GOM through the Yucatan Channel, 16 crossed the 200 m isobath into shallow waters, 12 of these around the Campeche Banks and the Florida Keys. The Campeche Banks would then be a likely area for habitation before further spreading into the GOM basin. Spreading from the Florida Keys to the interior of the GOM by advective transport alone would be very difficult. Only four drifters (0.2% of the data set) actually spread across the GOM basin to areas off northern Mexico, Texas, the Mississippi Bight and the west Florida shelf. Time scales for these drifters to cross the basin ranged between 1.5 to 3 months.

Considering the relatively small number of drifters from the north Atlantic data set that actually spread to shallow waters of the interior GOM, it would seem difficult for a non-indigenous species to spread into the GOM by advective transport. However, the arrival date of one of the drifters that entered the GOM from the Caribbean Sea and crossed onto shallow waters of the Mississippi Bight coincided almost exactly with the arrival date of an exotic jellyfish bloom in that area that did considerable ecological damage.

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